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# Development of new methods for determining the distribution of steel fibres in the hardened steel fibre reinforced concrete – possibilities of production and verification of test specimens

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**Abstract** Many research teams currently deal with the issue of determining the distribution of steel fibres in the hardened steel fibre reinforced concrete, both in terms of fibre concentration, and in terms of homogeneity of fibre distribution in the concrete. The basic element in the development of new non-destructive methods is the development of new principles and devices on adequate test specimens, in which precise spacial distribution of fibres, including the orientation of individual fibres, would be quite evident. The paper presents two technologically completely different possibilities of dealing with this issue. X-ray radiography is a traditional and long-established method, but in the field of construction, the authors' workplace is one of the few in the Czech Republic able to use it. The method of creating transparent specimens is completely unique, as it has been developed and is used only at the authors' workplace.

## 1. Introduction

Steel fibre reinforced concrete is nowadays a preferred material, starting from heavy-duty industrial floors, and ending with e.g. supporting structures of traffic facilities in the tectonically active areas.

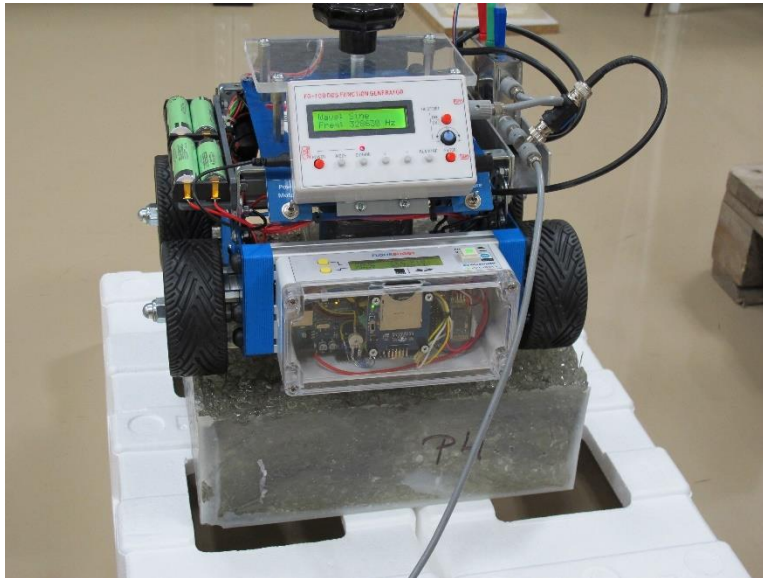
Despite the current progression of this material, the methods by which it is possible to determine the concentration of fibres in the finished structure and at the same time the homogeneity of its dispersion, lag behind. The existing normative regulations only deal with taking core samples from the structure and their subsequent crushing and determining the content of fibres in the specimen. No wonder that a number of research teams throughout the world are occupied with this issue and develop non-destructive methods based on various principles, which could be used in this area.

The department of the authors of this paper participates in the development and testing of experimental devices based on the principle of assessing the physical parameters describing the electromagnetic field. This field occurs in an area with electrically and electromagnetically conductive fibres in the tested composite after attaching an electromagnetic coil or permanent magnet. Although the basic principle of these newly designed devices is the same, the measuring methodologies themselves differ substantially and also their applicability is different.

An integral part of the development of new devices and methods is their testing. Testing requires test specimens with precisely defined properties. In this case it is necessary to use steel fibre reinforced concrete specimens of large dimensions - slabs. At the same time, however, it is necessary to have a precise idea of the concentration and distributional pattern (orientation) of fibres in any part of the test specimen. There are principally two ways of achieving this goal. Either to manufacture the specimen precisely according to the requirements, or to determine the required structural parameters in the finished test specimen. This paper does not deal with the manufacture of specimens with atypical



structure which differ from the common structure of steel fibre reinforced concretes made in the building practice, e.g. atypical orientation of fibres etc. [1-4].



**Figure 1.** Compact measuring and recording NDT device for the evaluation of the impedance module / phase of the monitored component (steel fibers) of the composite material specimen.

## **2. Variant 1 - Manufacture of specimens with precisely determined parameters with the possibility of their control during manufacture**

At the beginning of this section it is necessary to note that it is almost impossible to manufacture the required specimens with clearly defined parameters from concrete, if we have to be certain that the specimen does not deviate from the assumed and required limits in any of its parameters. Inhomogeneity of the dispersion of fibres in the laboratory specimens with a small volume is probable, it is caused both by a small volume of the prepared mixture, and e.g. by the edge effect in the proximity of walls of the mould etc. Even in the case of specially prepared specimens with atypical distribution of fibres, the use of concrete is inappropriate.

For the above mentioned cases, the authors of this paper developed a non-standard material, the structure of which simulates concrete, or steel fibre reinforced concrete, rather precisely, but which allows for corrections of the position of fibres, or detection of accidental inhomogeneities and problems which could degrade the test results of devices and methods.

The entry requirements on this material were as follows:

- Transparency to such an extent that it is possible to monitor the distribution of steel fibers with the considered thickness of the test slabs (within mm).
- Granularity structure similar to concrete which would guarantee similar parameters of dispersion and orientation of fibres as in real steel fibre reinforced concrete.
- Long workability time – high value of initial setting (in the order of hours) for the possibility of making corrections to the specimen structure.

Crucial for ensuring the required transparency is using a suitable binder and filler. At the same time, the binder should have a suitable consistency and the fractions of the filler should simulate, as precisely as possible, fine and coarse aggregates in the concrete mixture.

Clear crushed glass with suitable fractions, which is supplied to the glass art industry, turned out to be an ideal substitution for the aggregate. It became apparent that crushed glass with the required fractions and appropriate shape index is routinely available on the Czech market. The crushed glass

used was a waste product from the production of the Glass Sphere s.r.o. company. From the supplied mixed crushed glass, individual fractions were separated at first, and subsequently, mixtures were prepared corresponding to the fraction proportions of the aggregate from the original concrete. Before that, all parts of larger fractions which did not have a suitable shape index (flat plates), were removed from the crushed glass [5].

Epoxy resin was chosen as a suitable binder. In the selection of epoxy resins, several factors were taken into consideration. The lowest possible viscosity guaranteeing an ideal penetration of the mixture, an appropriate, relatively long period of workability, minimum volume changes. From the currently available resins, we chose the all-purpose resin called Biresin L84.

Another issue was the possibility of an appropriate moulding of specimens. We used a silicon sheet which allowed for a good separation of the epoxy mixture from the plywood mould. Alternatively, it is possible to use a self-adhesive metal sheet and a separator but silicone turned out to be more suitable. Nevertheless, both alternatives guarantee surface smoothness and protection of the mould itself from temperature - during resin curing, an exothermic reaction occurs and the specimens are heated to approximately 90°C [6].



**Figure 2.** Separated fractions of crushed glass.

After the tests, we first mixed a dry mixture of crushed glass, and subsequently added fibres in an appropriate amount, which was the optimum procedure. The mixing was carried out manually with a visual check of fibre homogeneity. The dry mixture was subsequently poured into the mould. In the end, the mixture was poured over with Biresin L84. Thanks to the appropriately selected low viscosity, penetration into the whole specimen was guaranteed, and at the same time, thanks to the long workability time, the majority of air bubbles disappeared spontaneously. The composition of the mixture is given in table 1, examples of the specific amount of fibres for some of the test specimens are given in table 2.

Note: The bulk density of the mixed fractions of glass in the shaken state was 1600 kg/m<sup>3</sup>, the porosity was 38.5%.

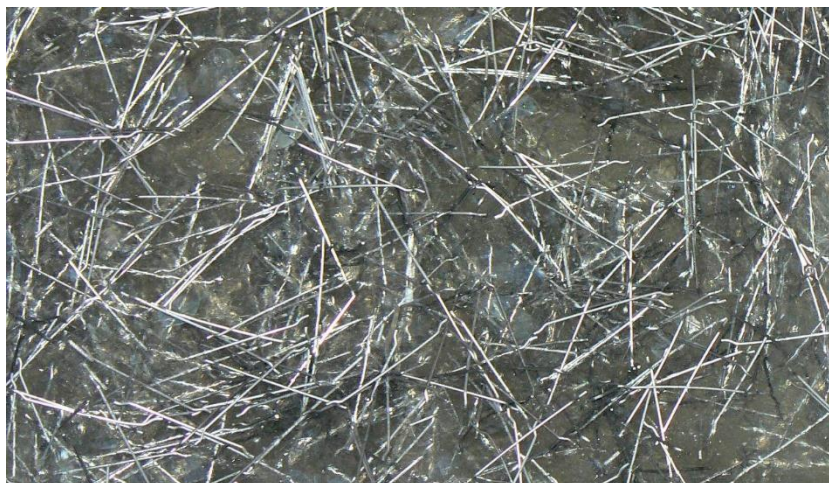
**Table 1.** Amount of glass and resin necessary for the proposed concrete mixture.

Material	Volume mass [kg/m <sup>3</sup> ]	Mass per 1m <sup>3</sup> of the mixture [kg]
Glass fraction 0 - 8	2600	960
Glass fraction 8 - 16	2600	640
Resin L84	700	269



**Table 2.** Amount of steel fibres necessary for individual mixtures.

Amounts of steel fibres for $V = 0.0135 \text{ m}^3$ (specimen with the dimensions of 300/300/150)			
Concentration (mass per $1 \text{ m}^3$ of the mixture)	FIBREX	TRI-TREG	DRAMIX
0.50% ( $39.25 \text{ kg/m}^3$ )	0.53 kg = 9 104 pcs	0.53 kg = 1 628 pcs	0.53 kg = 2 307 pcs
0.75% ( $58.88 \text{ kg/m}^3$ )	0.79 kg = 13 658 pcs	0.79 kg = 2 443 pcs	0.79 kg = 3 462 pcs
1.00% ( $78.50 \text{ kg/m}^3$ )	1.06 kg = 18 209 pcs	1.06 kg = 3 257 pcs	1.06 kg = 4 615 pcs
1.25% ( $98.13 \text{ kg/m}^3$ )	1.32 kg = 22 762 pcs	1.32 kg = 4 071 pcs	1.32 kg = 5 769 pcs
1.50% ( $117.75 \text{ kg/m}^3$ )	1.59 kg = 27 312 pcs	1.59 kg = 4 885 pcs	1.59 kg = 6 923 pcs

**Figure 3.** Mixture of a filler and fibres to be poured over with a binder.**Figure. 4:** After pouring the epoxy resin over the filler, the specimen becomes transparent and it is still possible to make corrections and simultaneously to visually check the resulting structure of the specimen. The specimen will keep its transparency even after its hardening.

### 3. Variant 2 - Manufacture of standard specimens with a subsequent check of their structure without the possibility of influencing the manufacture

At the beginning of this section it is necessary to note that it is almost impossible to manufacture the required specimens with clearly defined parameters from concrete, if we have to be certain that the specimen does not deviate from the assumed and required limits in any of its parameters. Inhomogeneity of fibre distribution is always a certain risk, which is substantial in the case of manufacturing specimens with the dimensional limitations. Yet, due to potential inhomogeneities, the subsequent testing of the newly developed probes could be completely misleading.

It is therefore necessary to check the actual distribution of fibres in the manufactured specimen. In the case of specimens with a width of up to 150 (max. 200) mm, the ideal method of checking is radiography with X-ray, i.e. a method based on the passage and attenuation of x-ray radiation. In the case of limit thicknesses of concrete, it is necessary to have an X-ray device, ideally with an X-ray tube voltage of 300 kV and an electric recording of the image for accelerating the activity (compared to the classical radiographic films [7,8]).

At the department of the authors of this paper, this measurement is done with the YXLON SMART 300 HP X-ray device, the passed and attenuated radiation is recorded with the memory film Dürer in combination with the CR35 NDT Plus scanner.

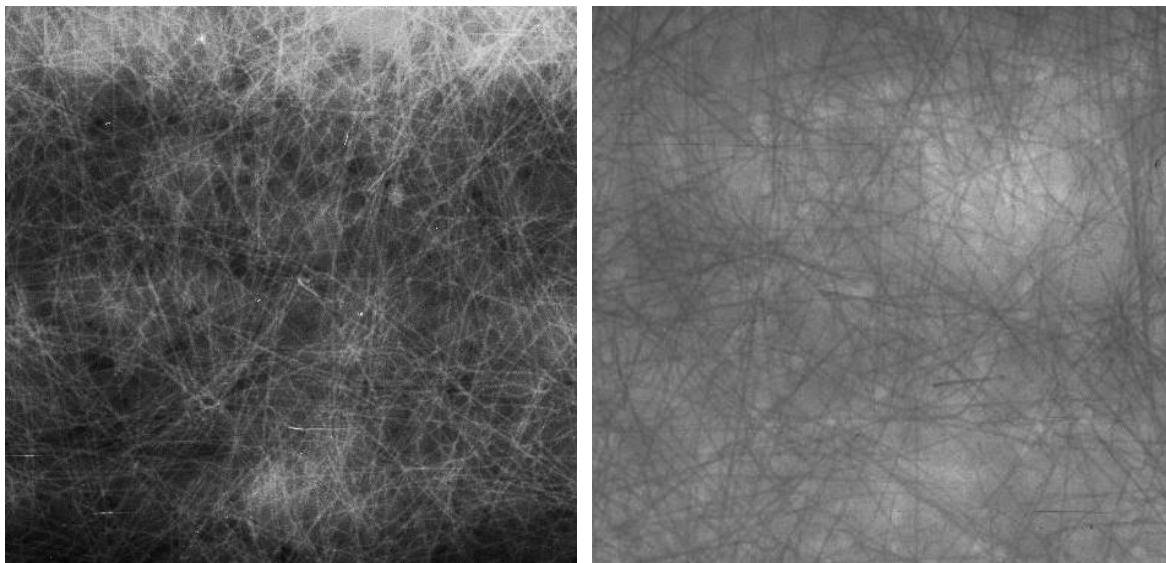
As an example, it is possible to present a radiographic inspection of the test steel fibre reinforced concrete slabs with the dimensions of 1000 x 1000 x 100 mm.

The focal distance chosen for the radiography of slabs was 1200 mm, the X-ray exposure parameters were determined according to the experimentally specified exposure nomogram and optimized in the following values:

Current on X-ray tube:	3 mA
Voltage on X-ray tube:	200 kV
Exposure time:	4.5 min

Due to the high dynamics of the blackening of memory films, small width of radiation beams and the influence of the dispersed radiation on the edges of the slabs, the individual pictures overlapped each other so that all the slab areas were evaluable.

When evaluating the images, it is appropriate to combine the classic and inverse display of the radiograms.



**Figure 5.** Example of a classic display of the radiogram where the blackening is proportionate to the radiation dose. Objects with a higher density are lighter, and on the right of the inverse variant of the radiogram, objects with a higher density are darker.

#### 4. Conclusion

The described methods appear to be ideal for the preparation of test specimens for creating new diagnostic methods for the determination of fiber reinforced concrete in terms of fiber concentration and dispersion. This is based on several years of experience with their application in authors' workplace. Especially the method of using transparent specimens is absolutely unique and, to the best of authors' knowledge, not used anywhere else in the world. On the other hand, the x-ray radiography is a well-known method. However, it is also scarcely used for these purposes as the number of institutions engaging in construction diagnostics which are in possession of the equipment needed for this method is small.

#### Acknowledgement

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